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“Master Degree in Innovative Technologies in Energy Efficient Buildings for Russian & Armenian Universities and Stakeholders

MARUEEB

Objectives:

Part I: Description of TEMP

Part II: Example of thermoeconomic analysis

Part III: Description of W-TEMP

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Part I:

THERMOECONOMIC ANALYSIS OF POWER PLANTS

Objectives

- Background
- TFA and TEMP approach
- Brief Analytical description
- Results for GT cycles
- Results for a sample STIG cogenerative cycle

Background

- **Two thermoeconomic approaches proposed in literature:**

  Thermoeconomic Functional Analysis (T.F.A.)

  aim: **Analysis + Optimisation**

  main authors: Tribus, Evans, Frangopoulus

  Exergetic Cost Theory

  aim: **Diagnostics**

  main authors: Tsatsaronis, Valero

- **TEMP (*Thermo-Economic Modular Program*) : a tool for thermo-economic analysis of thermal-energy systems**

  aim: **Analysis + Optimisation + Diagnostics**

  main authors: Massardo, Agazzani, Traverso

- **Environomics**

  aim: environmental impact analysis

  main authors: Massardo, Agazzani, Frangopuolus

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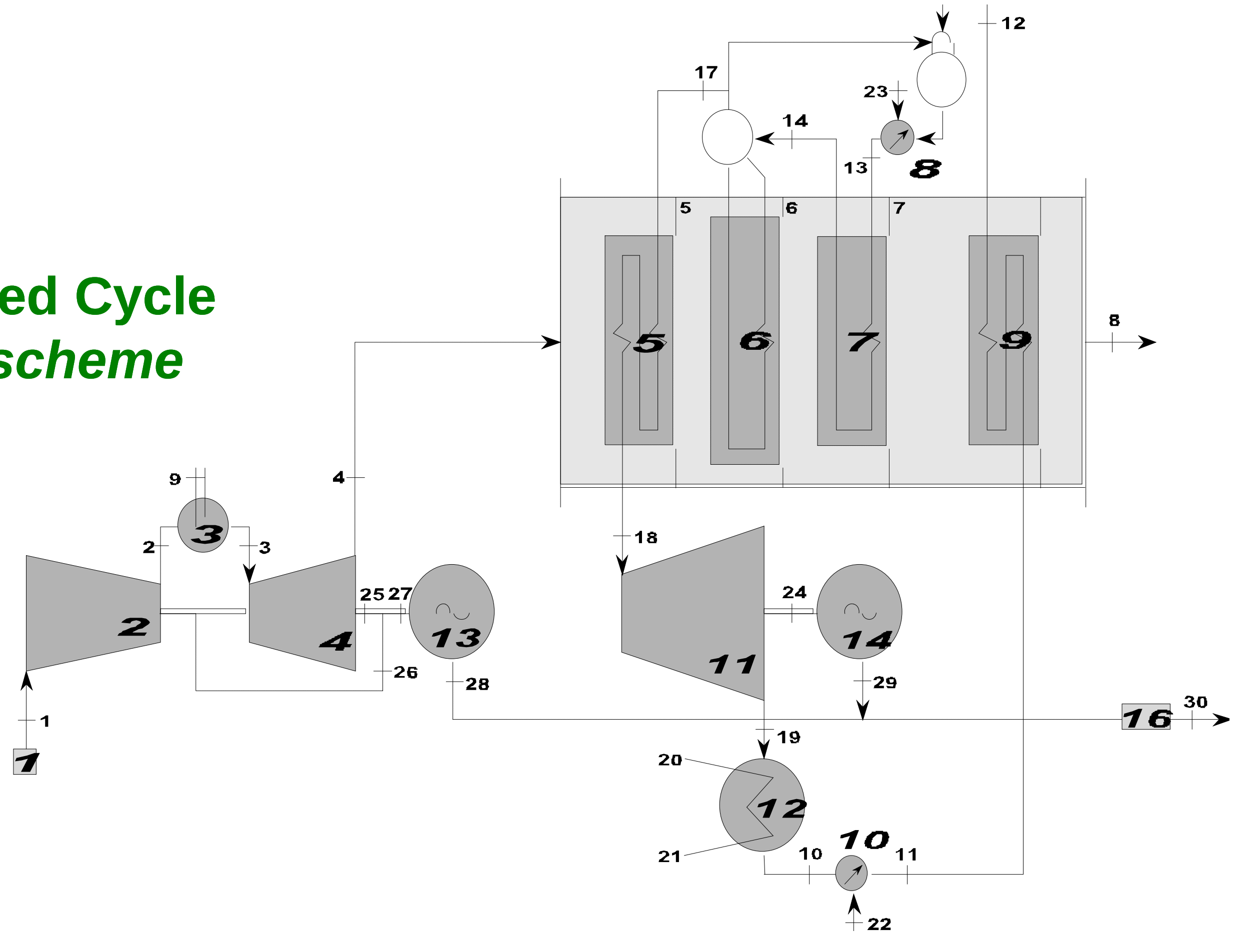
Thermoeconomic Functional Analysis (T.F.A.)

1 Combined Cycle
Physical scheme



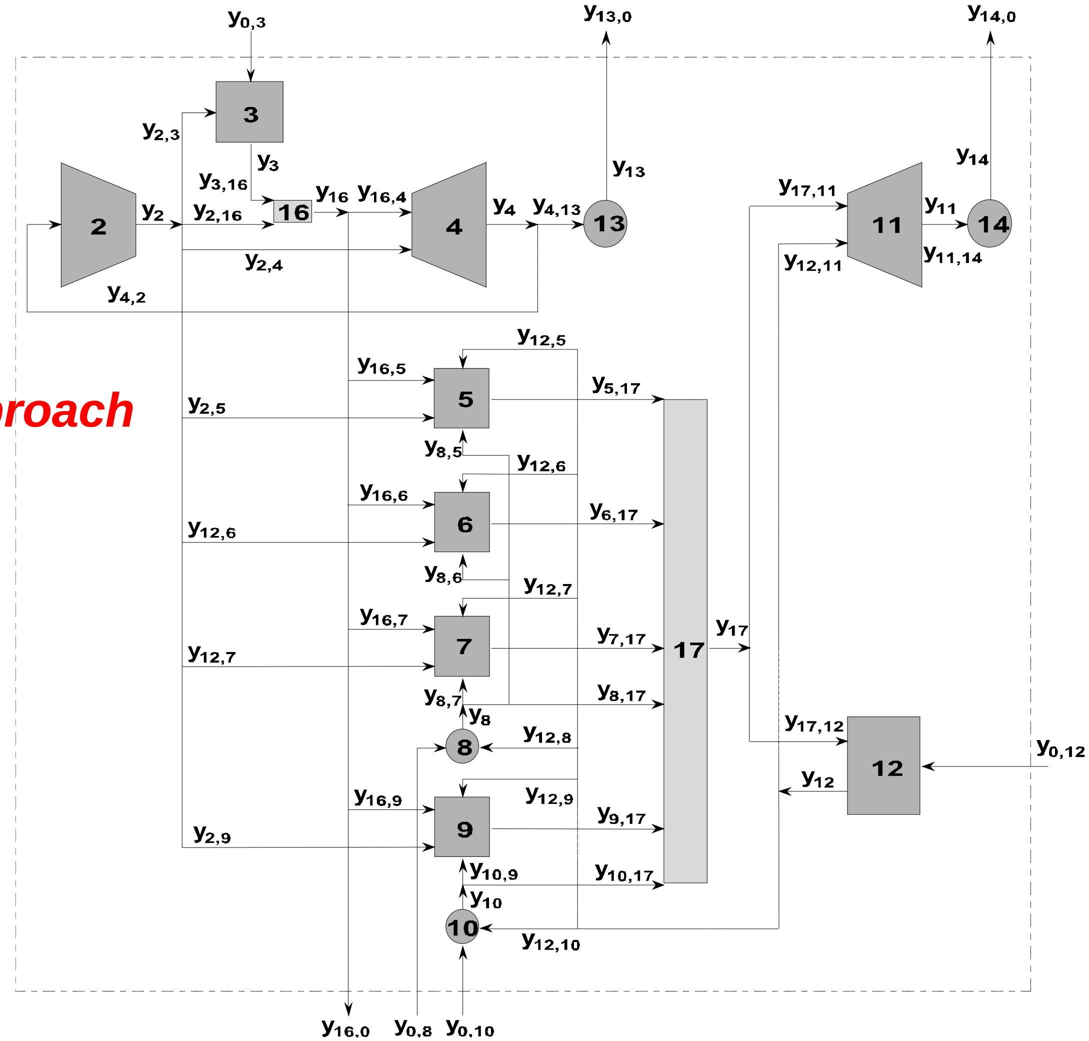
Thermoeconomic Functional Analysis (T.F.A.)

Functional Productive Diagram

1 Combined Cycle

Functional scheme

Academic traditional approach



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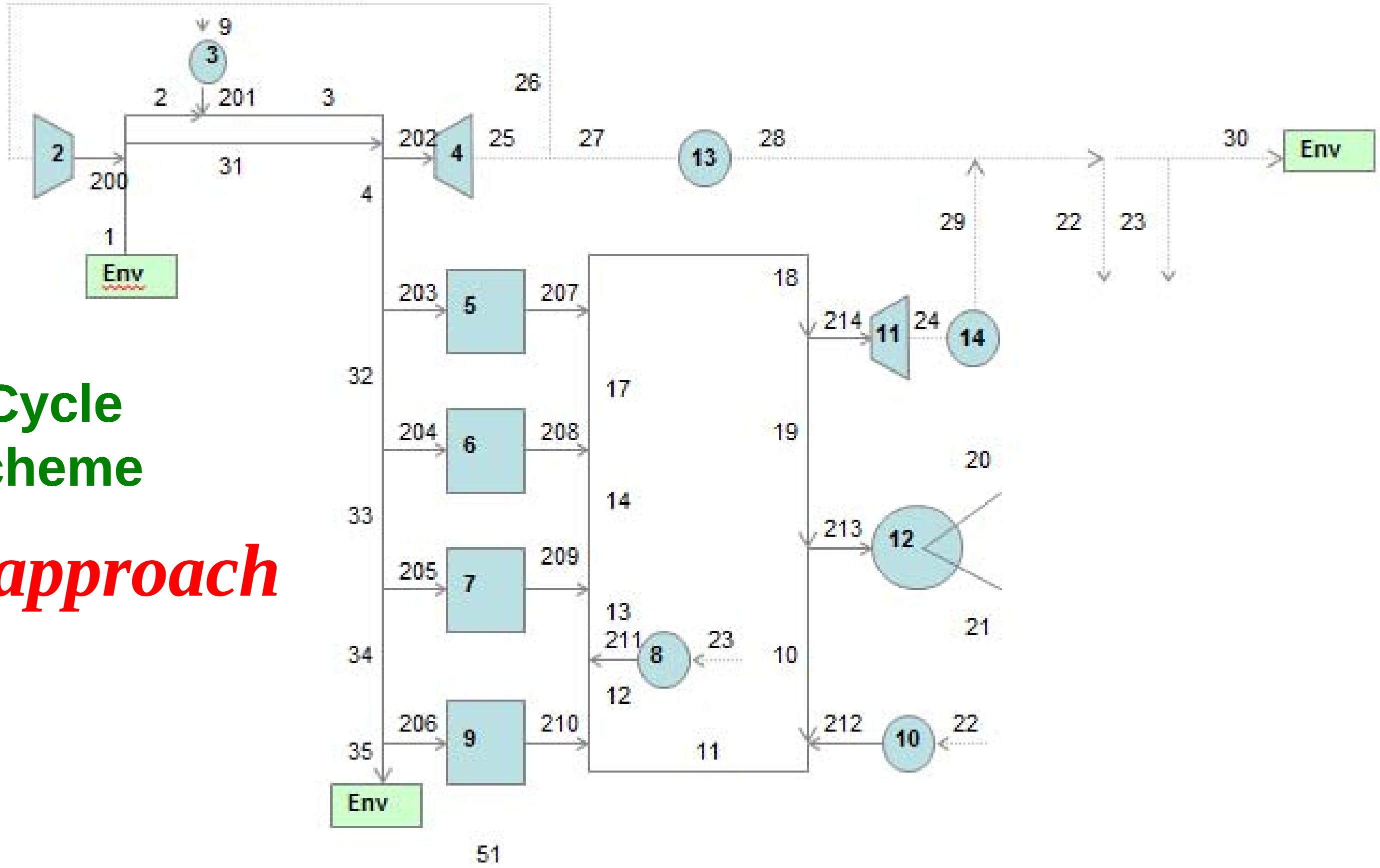
Thermoeconomic Functional Analysis (T.F.A.)

Functional Productive Diagram

1 Combined Cycle Functional scheme

WTEMP approach



Each component is characterized by single input and single output stream

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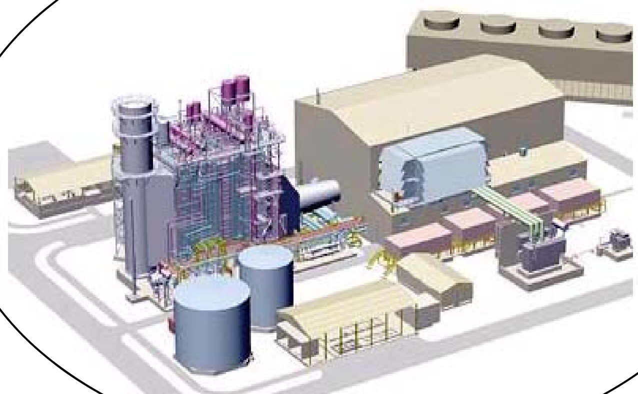
Thermoeconomic Functional Analysis

TEMP approach

Global ThermoEconomic Analysis



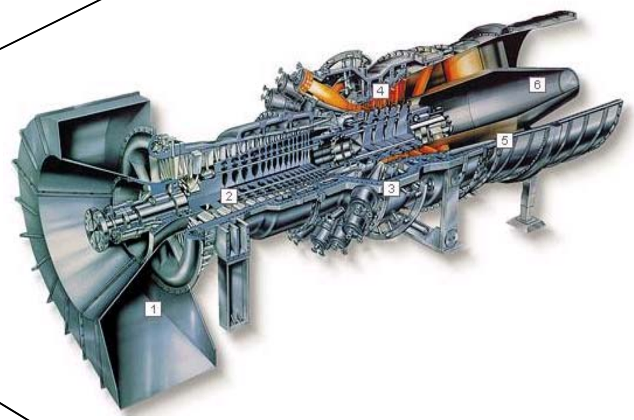
- **Turnkey Cost**
- **Fuel Cost**

} **Cost of Electricity (COE)**

- **Payback Period (PBP)**
- **Net Present Value (NPV)**
- **Internal rate of Return (IRR)**

} **Investment analysis**

Internal ThermoEconomic Analysis



- **Unit cost c**
- **Marginal unit cost λ**
- **Exergy cost y**

} **Diagnostics**

Global ThermoEconomic Analysis

- **Turn-key cost estimation (Total Capital Investment)**
- **Variable cost estimation (Fuel, Supply materials, Environmental costs)**
- Annual Total Revenue Requirement (TRR)
- Investment evaluation

Turnkey cost

```
______________________________
- TOTAL CAPITAL INVESTMENT -
______________________________

I. Fixed capital investment (FCI)
  A. Direct costs (DC)
    1. Onsite costs (ONSC)
      - Purchased equipment cost (PEC)
      - Purchased equipment cost installation (PECI)
      - Piping (PIP)
      - Instrumentation and controls (INCO)
      - Electrical equipment and materials (EEM)
    2. Offsite costs (OFSC)
      - Land (LAND)
      - Civil structural and architectural work (CSAW)
      - Service facilities (SF)
  B. Indirect costs (IC)
    1. Engineering and supervision (ES)
    2. Construction costs (COCO)
    3. Contingencies (CO)
II. Other Outlays (OO)
  A. Startup costs (SUC)
  B. Working capital (WC)
  C. Costs of licensing, research and development (LDR)
  D. Allowance for funds used during construction (AFUDC)
```

Variable costs

1) FUEL COSTS
2) OTHER SUPPLY MATERIALS COSTS (WATER, OIL, AMMONIA, …)
3) ENVIROMENTAL COSTS
3) O&M COSTS

Global ThermoEconomic Analysis

- Turn-key cost estimation (Total Capital Investment)
- Variable cost estimation (Fuel, Supply materials, Environmental co
- **Annual Total Revenue Requirement (TRR)**
- **Investment evaluation**

Total revenue requirement (TRR)

$$\textit{Total revenue requirement}_J = \textit{Total production cost}_J$$

$$\mathbf{TRR_J = TCR_J + ROI_{d,J} + ROI_{ps,J} + ROI_{ce,J} +}$$

$$\mathbf{+ O\&M_J + OTXI_J + ITX_J +}$$

$$\mathbf{+ FuelCost_J + MatCost_J + EnvirCost_J}$$

EnvirCost:
- **Carbon Tax**
- **Green Certificate**
- **Emission Trading**

Investment analisys methods

1) Average rate of return **(ARR)**
2) Payback Period **(PBP)**
3) Discounted Payback Period **(DPBP)**
4) Net Present Value **(NPV)**
5) Internal rate of Return **(IRR)**

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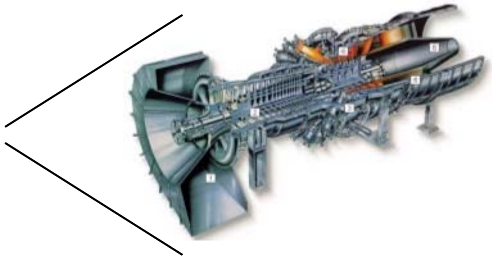
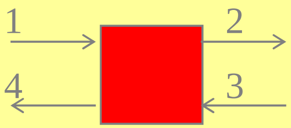
Internal ThermoEconomic Analysis

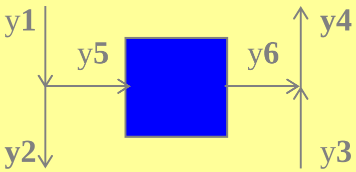


Physical Scheme



Heat Exchanger

Functional Scheme



$$c_6 y_6 = c_5 y_5 + C\$_{hex}$$

How to calculate?

Mass conservation

Momentum conservation

Energy conservation

+

Cost conservation

Exergy flow y_r [kW]

y_r expresses the exergy flow associated to the functional flow y_r

Unit cost c_r [$/kJ]

c_r expresses the amount of resources (in monetary terms) consumed to obtain the functional flow y_r

Exergy allows to include cost variables in addition to conventional balances

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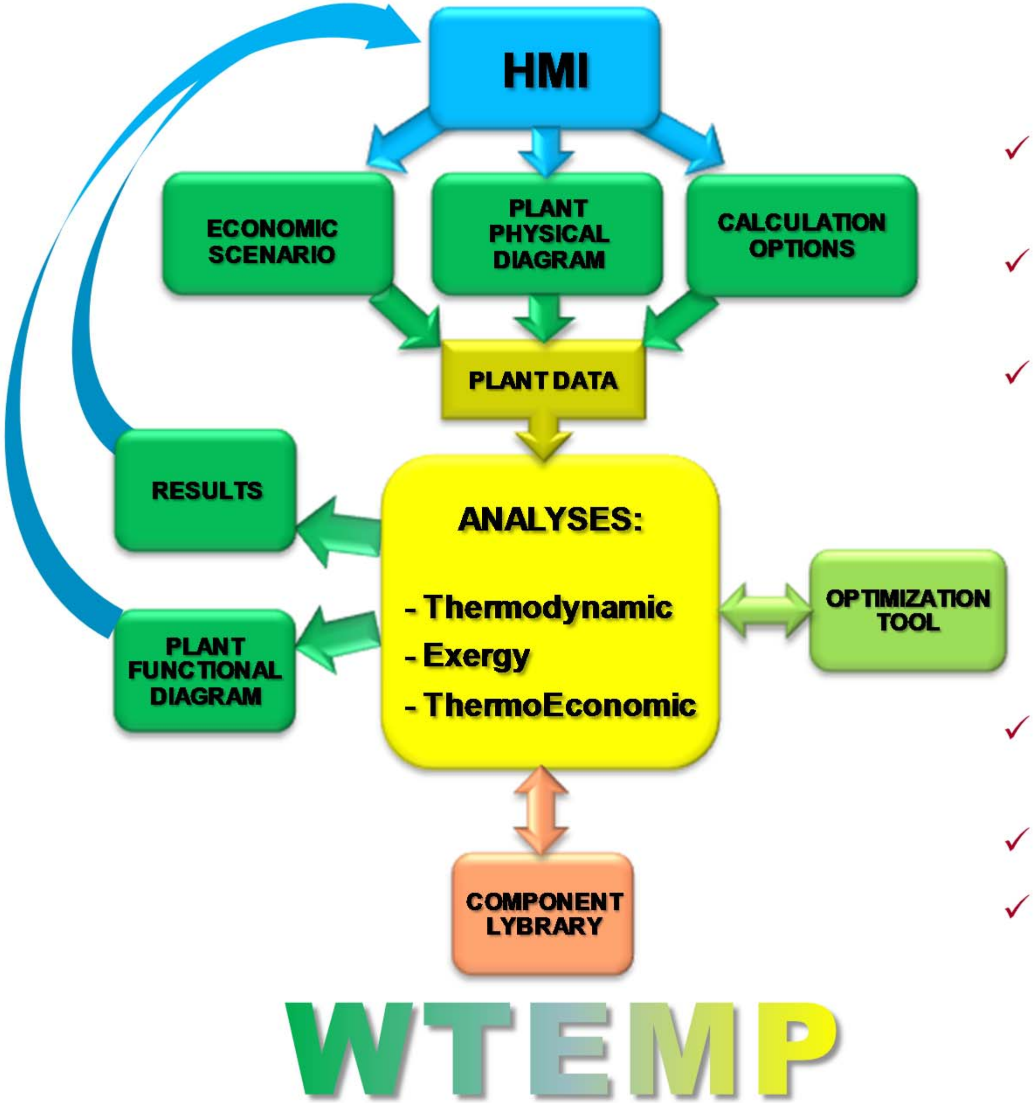
W-TEMP software (Web ThermoEconomic Modular Program)



Main Challenges:

- ✓ **Simulating complex system** with hundreds of components and variables
- ✓ **Defining the proper mathematical model** for representing each component behaviour
- ✓ **Assessing the influence of parameters** on thermodynamic and economic plant results

Sequential Method:

- ✓ **Thermodynamic analysis** (efficiency, fuel consumpt., etc.)
- ✓ **Exergy analysis** (exergy flows, losses)
- ✓ **Thermoeconomic analysis** (CAPEX & OPEX, IRR and NPV, internal flow costing)

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AVAILABLE MODULES

Libraries:

Conventional gas

Advanced gas and reactors

Steam

Power and Heat

Miscellaneous

1.	Steam/Water Inlet
2.	Steam/Water Mixer
3.	Steam/Water Flow Splitter
4.	Steam Turbine
5.	CO2 Removal by Physical Absorption
6.	H2S Removal by Physical Absorption
7.	Sulfur recovery process
8.	Degasator
9.	Pump
10.	Thermal user
11.	Condenser
12.	Electrical Engine
13.	Alternator
14.	Compressor
15.	Combustor
16.	Gas Expander
17.	Gas Mixer
18.	Gas Flow Splitter
19.	Air Inlet
20.	Steam/Water Pressure and Enthalpy Loss
21.	Parallel Flow Splitter
22.	Economiser Gas/Water for HRSG
23.	Evaporator Gas/Water for HRSG
24.	Superheater Gas/Water for HRSG
25.	Gas/Steam Mixer
26.	Evaporator/Deaerator Gas/Water
27.	Steam Generator
28.	Entrained Bed Coal Gasifier
29.	Electrical Power Junction
30.	Electrical Power Branch Point

31.	FGD (Flue Gas Desulphurisation)
32.	SCR (Selective Catalytic Reaction)
33.	Electrical Power Inlet
34.	Gas Exhaust
35.	Sequestration CO2-Absorbation with amines
36.	Gas Pressure and Temperature Loss
37.	Recuperator
38.	Fuelcell SOFC
39.	Reformer CH4 and Jet-A
40.	Mechanical Power Junction
41.	Mechanical Power Branch Point
42.	Electrical Power Outlet
43.	FGC (Flue Gas Condenser)
44.	Steam/Water Outlet
45.	Reformer-CH3OH
46.	Internal Combustion Engine
47.	Intercooler with Condensate Separator
48.	Partial Oxidator
49.	Gas/Water Mixer
50.	Biomass Gasifier
51.	Reactor Water-Gas Shift
52.	Water/water Exchanger
53.	Water Treatment
54.	Fuelcell MCFC
55.	Composition Defined Inlet
56.	Reformer-CH4 sensible
57.	Catalytic Burner
58.	Pressure Swing Adsorption (PSA)
59.	Fuelcell MCFC with temperature iteration
60.	OXIPAR

61.	Mechanical Power Inlet
62.	Air Separation Unit (ASU)
63.	Saturator/Scrubber
64.	Non-Specified Composition Inlet
65.	Non-Specified Composition Outlet
66.	Water hot/gas cold Exchanger
67.	Steam hot/gas cold Exchanger
68.	Hydrogen separation membrane
69.	Coal Inlet
70.	Pyrolysis reactor
71.	Cyclone
72.	Char Combustor
73.	Ejector
74.	Tar Cracking
75.	Coal/Biomass Gasifier (Gibbs reactor)
76.	Biomass Inlet
77.	Distributed Generation user
78.	Water regeneration
79.	Reformer CH4, kinetic and heat exchanger
80.	Pyrolizer
81.	Cooled gas stage
82.	Dryer
83.	Bottoming Cycle
84.	Desalination unit
85.	Absorption Chiller
86.	Fuel Processor
87.	
88.	
89.	
90.	

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- TOTAL CAPITAL INVESTMENT -

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Percentage Approach

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Depreciation methods

n°	Method	f_j	$\sum_{z=1}^{j} f_z$
1.	Straight line	$1/n$	j/n
2.	Sum-of-the-years digits	$2/n \cdot (n+1-j)/(n+1)$	$j \cdot (2n+1-j)/[n(n+1)]$
3.	Double declining balance (n>=3) *	$2/n \cdot [(n-2)/n]^{j-1}$	$1-[(n-2)/n]^{j}$
4.	125% declining balance *	$1.25/n \cdot [(n-1.25)/n]^{j-1}$	$1-[(n-1.25)/n]^{j}$
5.	Sinking fund	$r_i \cdot (1+r_i)^{j-1}/[(1+r_i)^{n}-1]$	$[(1+r_i)^{j}-1]/[(1+r_i)^{n}-1]$

(n = Book Life; r_i = Inflation Rate)

* Salvage must be equal to zero and $\sum_{z=1}^{n} f_z < 1$

Financing methods

1) DEBT financing
   Borrowing capital from banks, by selling bonds,...

2) COMMON EQUITY financing
   Sale of common equity stock

3) PREFERRED STOCK financing
   Sale of preferred equity stock

4) A COMBINATION of 1-3
   By mean of financing fraction F:

   F_d F_ce F_ps

   where:

   F_d + F_ce + F_ps = 1

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Taxes & Insurances

1) PROPERTY TAXES & INSURANCES

Evaluated as percentage of Fixed Capital Investment (out of Land)

$$\mathbf{OTXI_J = f_{OTXI} \cdot (FCI - LAND)}$$

2) INCOME TAXES

Evaluated by multiplying the income tax rate (**t**) by the taxable income (**TXI**) which is the difference between total revenue and all tax-deductible expenditures.

$$\mathbf{ITX_J = t \cdot TXI_J}$$

Variable costs

1) FUEL COSTS

$FuelCost_J$ = f (annual fuel consumption, fuel price)

2) OTHER SUPPLY MATERIALS COSTS (AIR, WATER, OIL,…)

$MatCost_J$ = f (annual consumption, material price)

3) ENVIROMENTAL COSTS

$EnvirCost_J$ = f (annual emissions rate, environmental penalty)

Total revenue requirement (TRR)

The annual *total revenue requirement* for a system is the revenue that must be collected in a given year through the sale of all products to compensate the system operating company for all expenditures incurred in the same year.

$$\textit{Total revenue requirement}_J = \textit{Total production cost}_J$$

$$\mathbf{TRR_J = TCR_J + ROI_{d,J} + ROI_{ps,J} + ROI_{ce,J} +}$$

$$\mathbf{+ O\&M_J + OTXI_J + ITX_J +}$$

$$\mathbf{+ FuelCost_J + MatCost_J + EnvirCost_J}$$

Annual profit

1) GROSS PROFIT

Is the difference between the annual total revenue collected ($\mathbf{Rv_J}$) and the annual total revenue requirement ($\mathbf{TRR_J}$)

$$GP_J = Rv_J - TRR_J$$

2) NET PROFIT

Is the actual profit, out of income taxes

$$NP_J = GP_J * (1 - t)$$

3) ANNUAL CASH FLOW

$$CFN_J = NP_J + TCR_J$$

Investment analisys methods

1) Average rate of return **(ARR)**

$$ARR_j = NP_j / TCI$$

2) *Payback Period* **(PBP)**

$$TCI = \sum_{j=1}^{PBP} CFN_j$$

3) *Discounted Payback Period* **(DPBP)**

$$TCI = \sum_{j=1}^{PBP} [CFN_j / (1+ r_{NPV})^j]$$

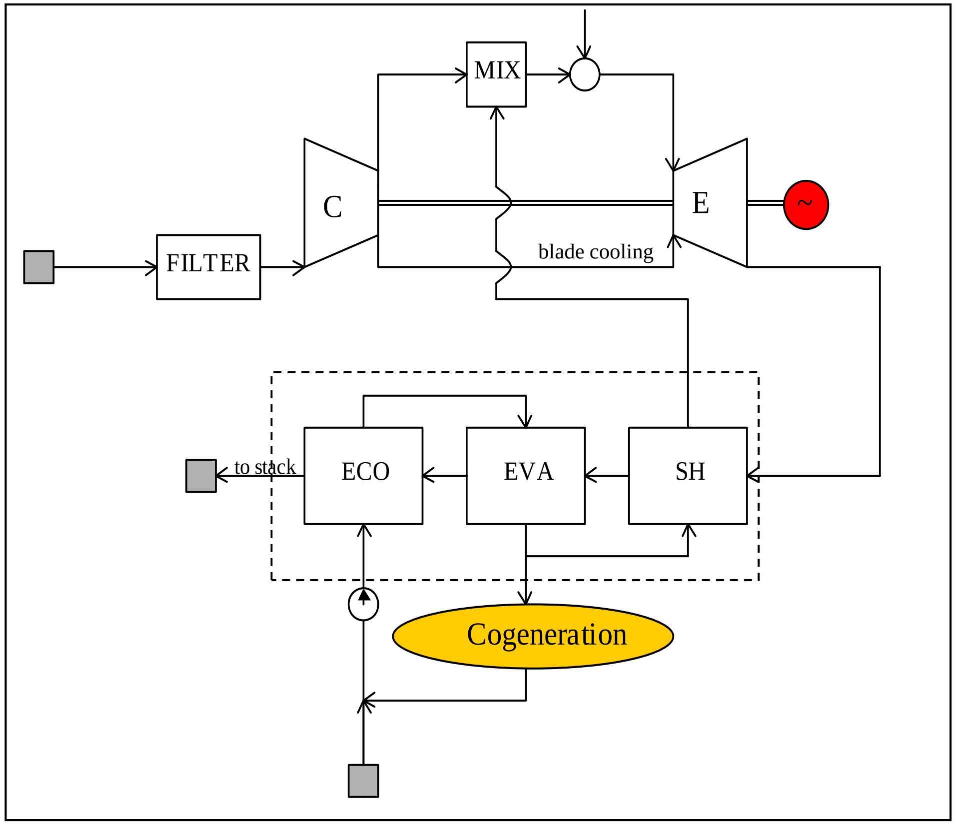
4) *Net Present Value* **(NPV)**

$$NPV = \sum_{j=1}^{BL} [CFN_j / (1+ r_{NPV})^j] - TCI$$

5) *Internal rate of Return* **(IRR)**

$$\sum_{j=1}^{BL}[CFN_j / (1+IRR)^j] - TCI = 0$$

1PL Cogenerative STIG cycle



Cycle main data:

- –Pressure ratio 15
- –TIT 1200°C
- –Evaporator pressure 23 bar

Cycle performance:

- –Electrical Power 50MW
- –Thermal Power 30MW
- –Electrical Efficiency 42%
- –Thermal Efficiency 65%

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OUTPUT

Through Life cost

Current Money

Year		TCR [$/y]	ROI [$/y]	ITX [$/y]	OTXI [$/y]	O&M [$/y]	FuelC [$/y]	EnvC [$/y]	TRR [$/y]	Rev	GP	NP	CHFs
2003	1	1474029	1350338	-13883	430288	467529	7994454	0	11702755	20029858	8327103	5828972	7303001
2004	2	1474029	1263001	-33940	430288	479217	8231859	0	11844454	20630754	8786300	6150410	7624438
2005	3	1474029	1175665	-53997	430288	491197	8476386	0	11993568	21249676	9256108	6479276	7953304
2006	4	1474029	1088330	-74055	430288	503477	8728249	0	12150317	21887167	9736849	6815795	8289823
2007	5	1474029	1000994	-94112	430288	516064	8987667	0	12314929	22543782	10228852	7160197	8634225
2008	6	1474029	913656	-114169	430288	528966	9254869	0	12487638	23220095	10732457	7512720	8986748
2009	7	1474029	826320	-134227	430288	542190	9530086	0	12668686	23916698	11248012	7873608	9347637
2010	8	1474029	738985	-154284	430288	555745	9813560	0	12858321	24634199	11775878	8243114	9717143
2011	9	1474029	651649	-174341	430288	569638	10105538	0	13056799	25373225	12316425	8621498	10095526
2012	10	1474029	564312	-194398	430288	583879	10406275	0	13264384	26134421	12870037	9009026	10483055
2013	11	805023	476976	454550	430288	598476	10716034	0	13481347	26918454	13437107	9405975	10210998
2014	12	805023	429278	443596	430288	613438	11035086	0	13756709	27726008	13969298	9778509	10583531
2015	13	805023	381581	432642	430288	628774	11363710	0	14042017	28557788	14515771	10161039	10966062
2016	14	805023	333883	421688	430288	644494	11702193	0	14337568	29414522	15076954	10553868	11358890
2017	15	805023	286186	410734	430288	660606	12050830	0	14643665	30296957	15653292	10957304	11762327
2018	16	805023	238488	399780	430288	677121	12409926	0	14960625	31205866	16245241	11371669	12176691
2019	17	805023	190790	388826	430288	694049	12779794	0	15288770	32142042	16853272	11797290	12602313
2020	18	805023	143093	377872	430288	711400	13160759	0	15628435	33106303	17477869	12234508	13039531
2021	19	805023	95395	366918	430288	729185	13553153	0	15979962	34099492	18119530	12683671	13488694
2022	20	805023	47697	355964	430288	747415	13957319	0	16343706	35122477	18778771	13145140	13950163

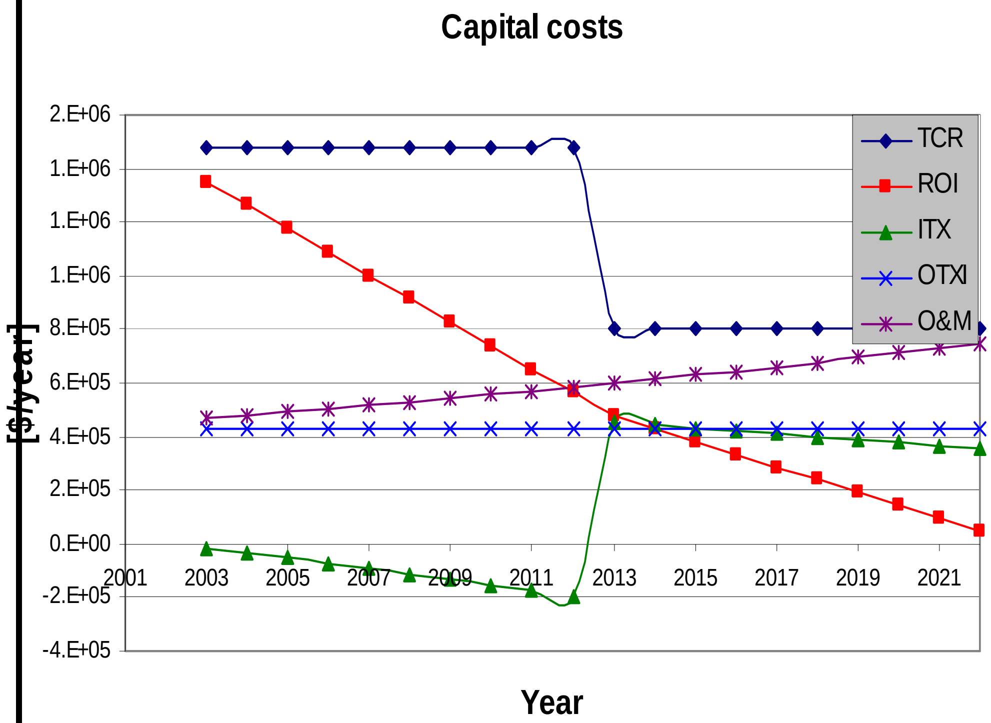
Constant Money

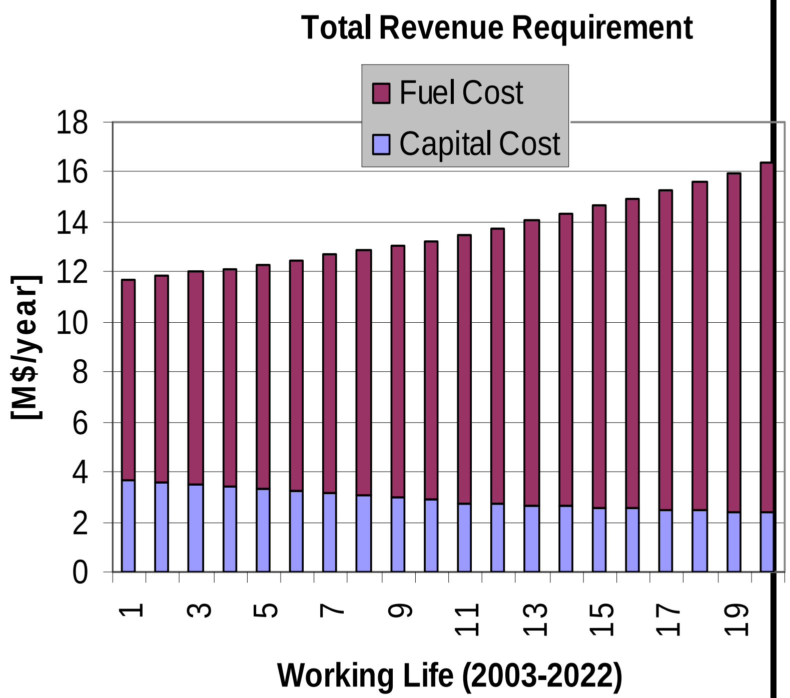
Reference Year= 2001

Year		TCR [$/y]	ROI [$/y]	ITX [$/y]	OTXI [$/y]	O&M [$/y]	FuelC [$/y]	EnvC [$/y]	TRR [$/y]	Rev	GP	NP	CHFs
2003	1	1403002	1172822	-13214	409554	445001	7609237	0	11138850	19064707	7925857	5548100	6951101
2004	2	1368782	1065095	-31517	399565	445001	7644100	0	10998753	19157706	8158953	5711267	7080049
2005	3	1335397	961925	-48919	389819	445001	7679187	0	10865581	19251158	8385577	5869904	7205301
2006	4	1302826	863154	-65453	380312	445001	7714500	0	10739110	19345066	8605956	6024169	7326996
2007	5	1271050	768628	-81152	371036	445001	7750038	0	10619125	19439432	8820307	6174215	7445265
2008	6	1240049	678200	-96047	361986	445001	7785799	0	10505416	19534259	9028843	6320190	7560239
2009	7	1209804	591726	-110166	353157	445001	7821785	0	10397781	19629548	9231767	6462237	7672041
2010	8	1180296	509067	-123539	344544	445001	7857995	0	10296022	19725302	9429279	6600495	7780792
2011	9	1151509	430088	-136195	336140	445001	7894430	0	10199951	19821523	9621572	6735100	7886609
2012	10	1123423	354658	-148160	327942	445001	7931088	0	10109381	19918213	9808832	6866182	7989605
2013	11	598579	311407	337983	319943	445001	7967970	0	10024135	20015375	9991240	6993868	7592447
2014	12	583980	270055	321794	312140	445001	8005077	0	9979397	20113011	10133614	7093530	7677509
2015	13	569736	230535	306193	304526	445001	8042407	0	9937918	20211123	10273206	7191244	7760980
2016	14	555840	192782	291161	297099	445001	8079961	0	9899597	20309714	10410117	7287082	7842923
2017	15	542283	156733	276681	289853	445001	8117739	0	9864338	20408786	10544448	7381113	7923397
2018	16	529057	122329	262733	282783	445001	8155742	0	9832049	20508341	10676292	7473405	8002461
2019	17	516153	89508	249302	275886	445001	8193969	0	9802638	20608382	10805743	7564020	8080173
2020	18	503564	58217	236369	269157	445001	8232420	0	9776019	20708910	10932891	7653024	8156588
2021	19	491282	28399	223919	262592	445001	8271096	0	9752106	20809929	11057823	7740476	8231758
2022	20	479299	0	211936	256187	445001	8309996	0	9730818	20911441	11180623	7826436	8305735

THROUGH LIFE COST

(Current Money)



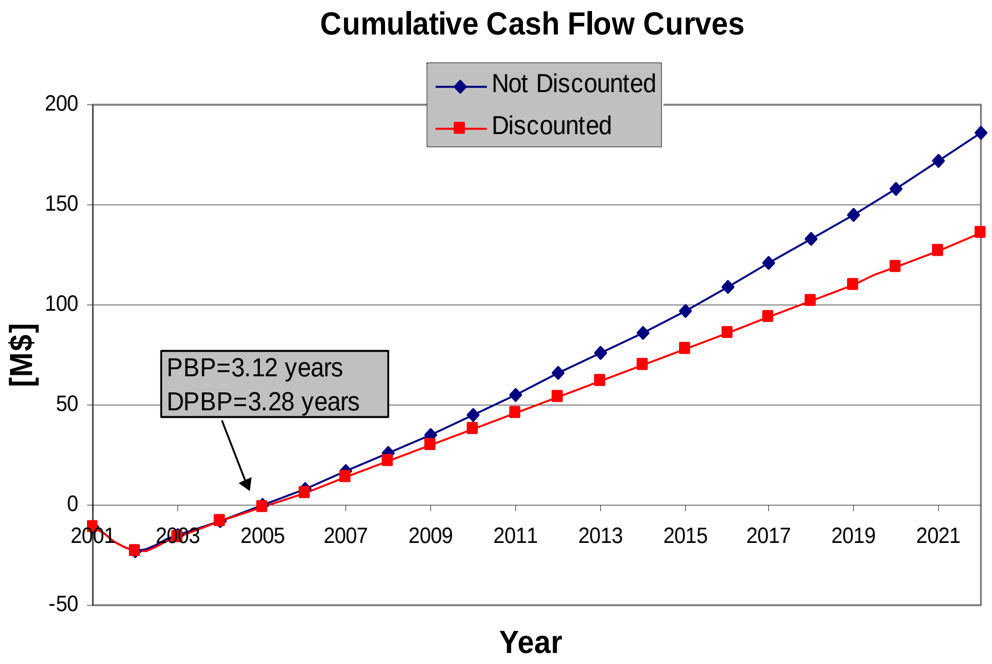


INVESTMENT ANALYSIS

(Current Money)

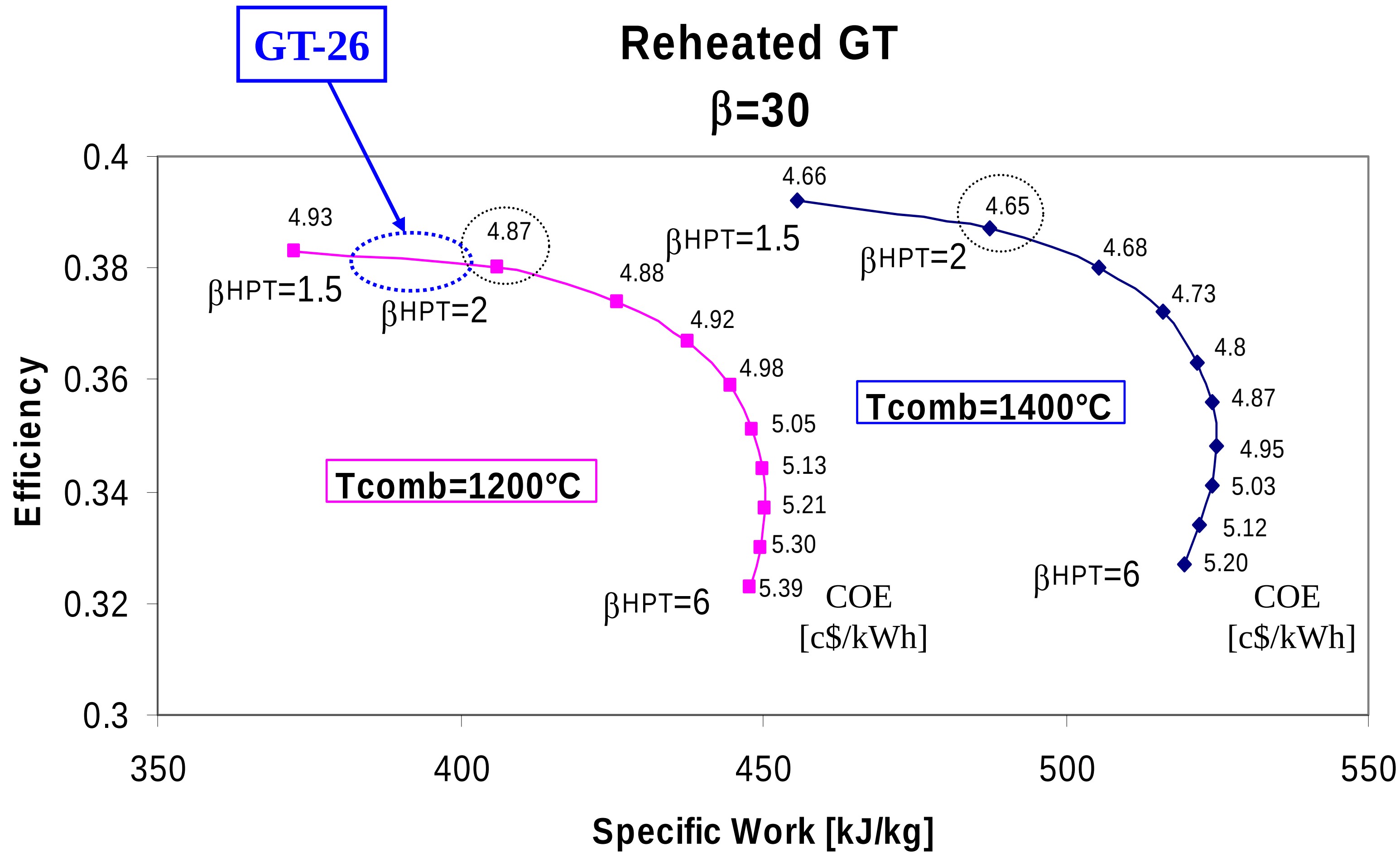
Investment analysis parameters

•Pay Back Period (PBP)	**3.12**	y
•Discounted PBP (DPBP)	**3.28**	y
•Net Present Value (NPV)	**128.6**	M$
•Benfit Cost Ratio (BCR)	**6.64**	
•Net BCR (NBCR)	**5.64**	
•Eckstein BCR (EBCR)	**2.01**	
•Internal Rate of Return (IRR)	**34.4**	%



GAS TURBINE CYCLES

Reheated cycle (Sequential combustion)



TPG

Part I:

THERMOECONOMIC ANALYSIS OF POWER PLANTS

CONCLUSIONS

- **Thermoeconomics is a complex and powerful method to analyse, optimise and diagnose energy systems.**
- **Thermoeconomics analyses energy plants basing on Functional Productive Diagram, in which physical and functional exergy flows are reported.**
- **TEMP is flexible code for thermoeconomic analysis of conventional and advanced energy systems**
- **TEMP allows the thermoeconomic optimisation in on-design conditions to be carried out.**

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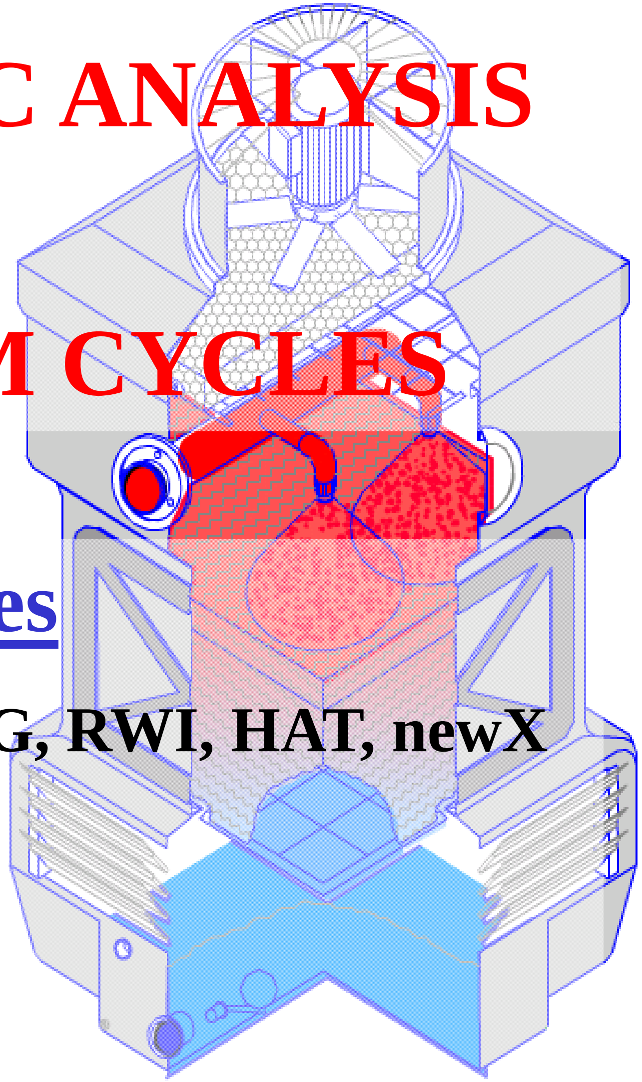
Part II:

THERMOECONOMIC ANALYSIS

OF

MIXED AIR-STEAM CYCLES

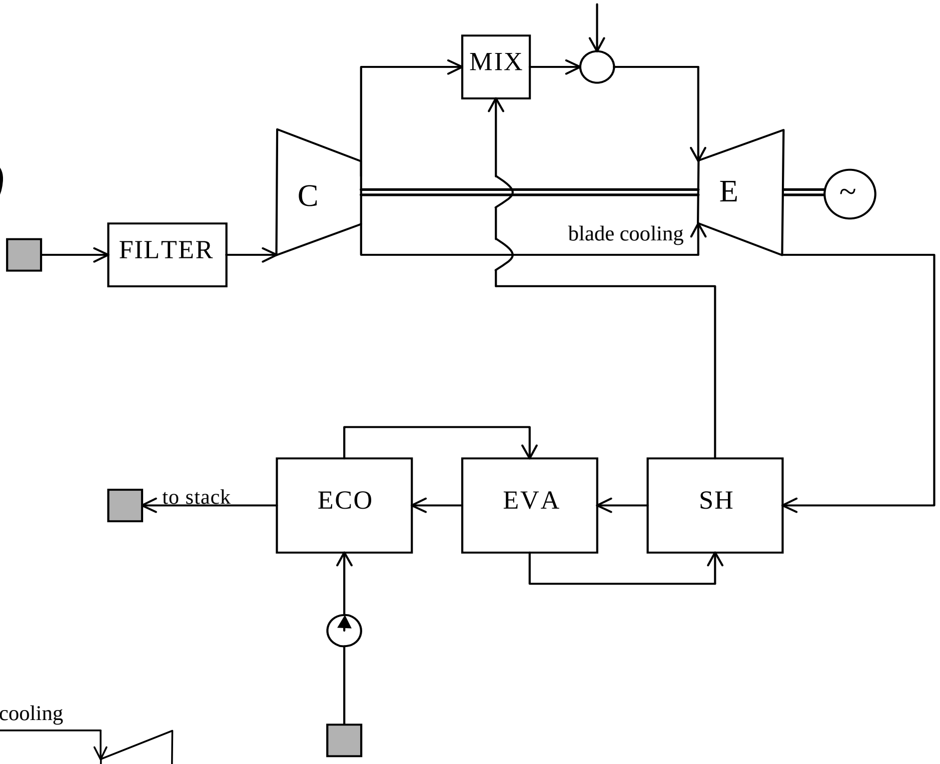


Objectives

- Mixed air-steam cycles: STIG, RWI, HAT, newX
- newX cycle assessment
- Thermoeconomic results

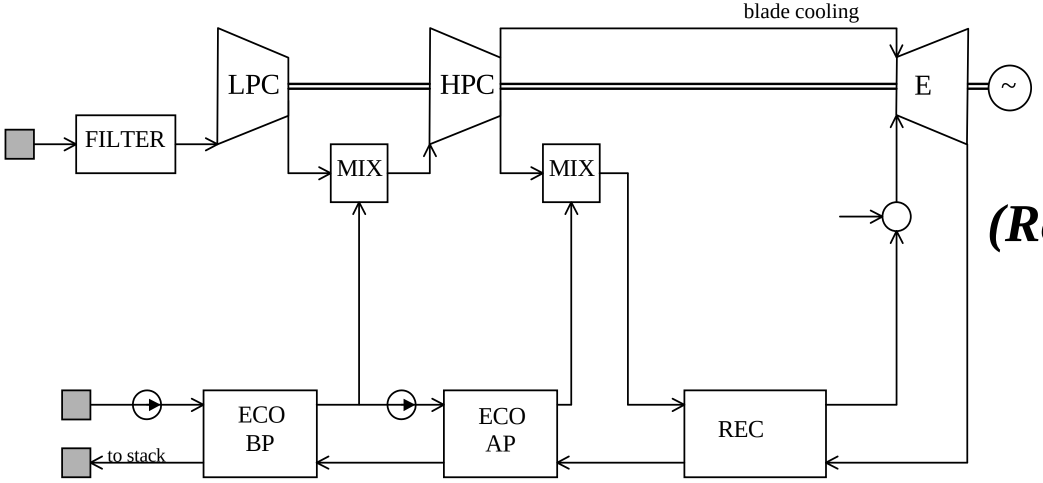
STIG

(STeam Injected Gas turbine cycle)



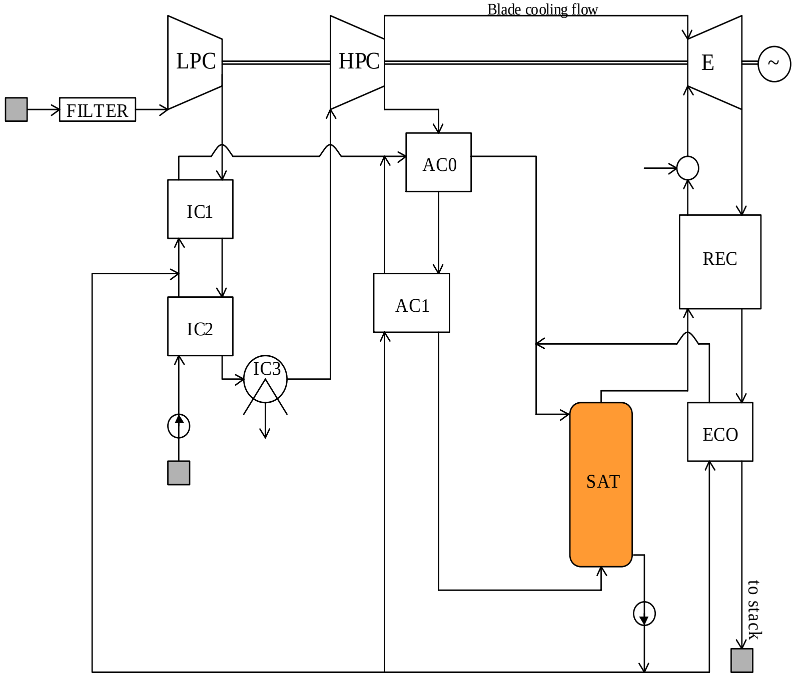
RWI

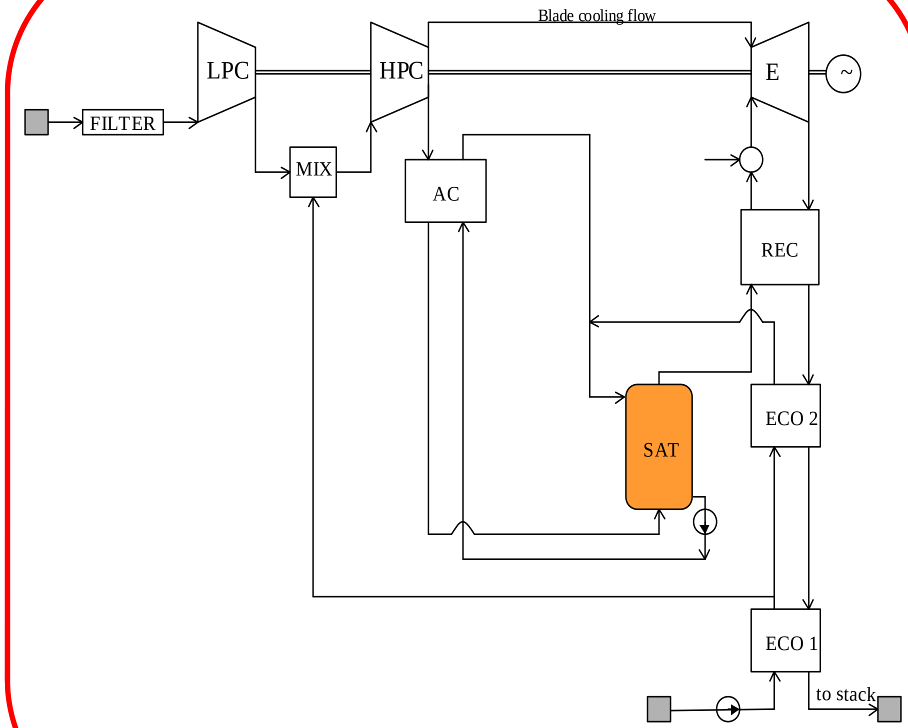
(Regenerated Water Injected cycle)



HAT

(Humid Air Turbine cycle)





HAWIT

(Humid Air Water Injected Turbine cycle)

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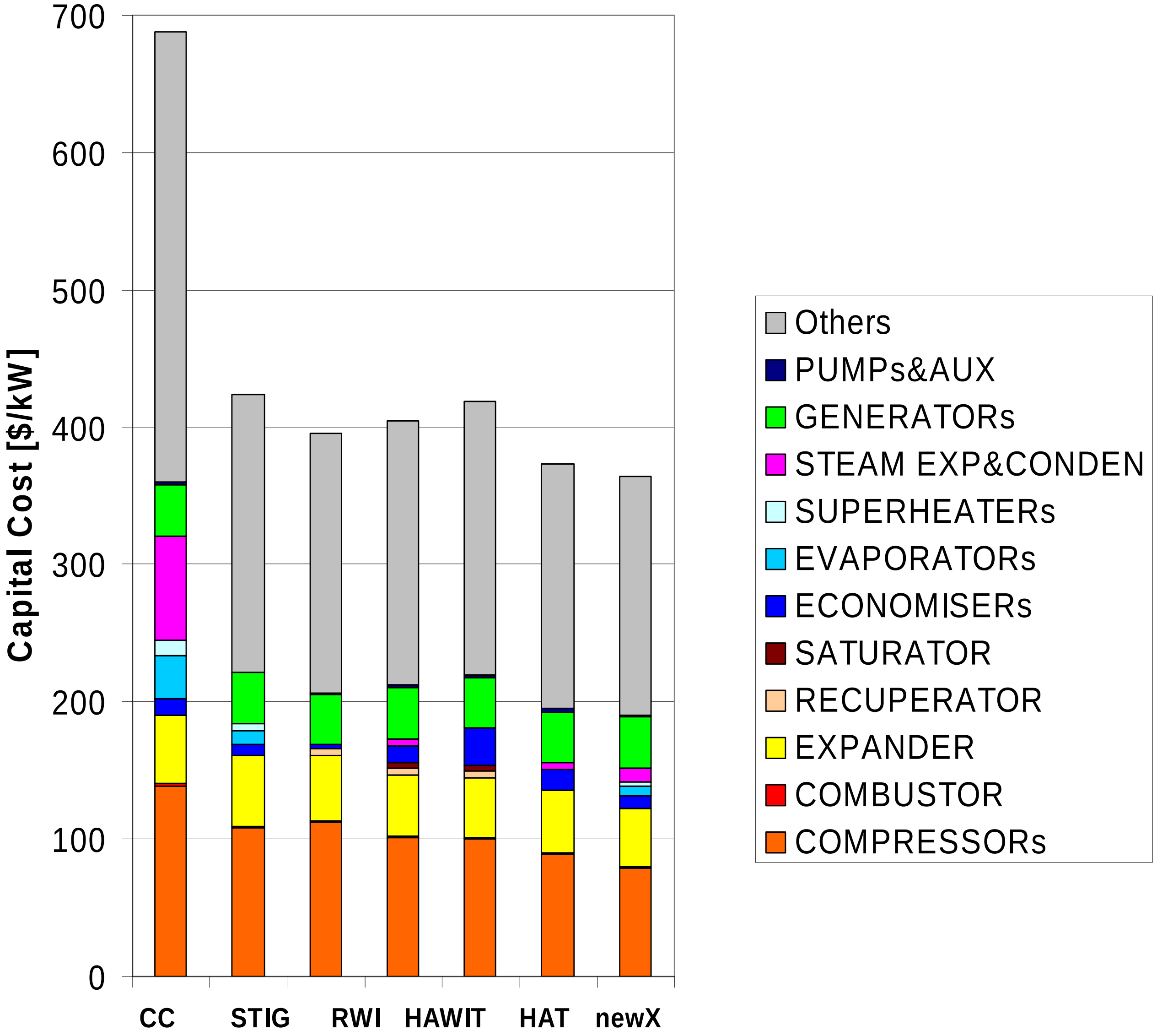
CAPITAL COST ANALYSIS (50MWe)



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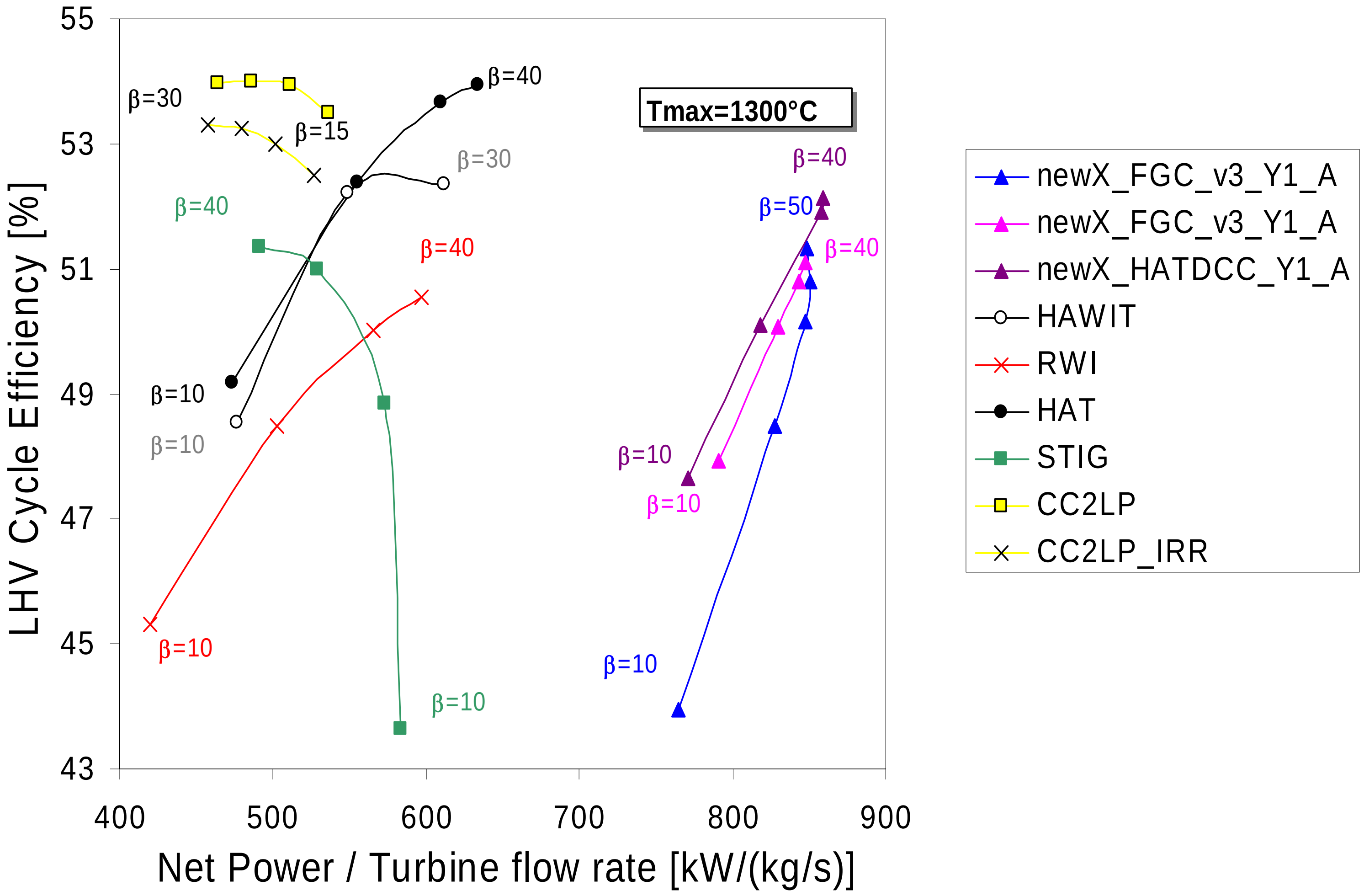
THERMODYNAMIC RESULTS (50MWe)



THROUGH LIFE COST ANALYSIS (50MWe)

```
'Economic Data Reference Year (1Jan)---------------------- =' 2000
'Inflation [%] ------------------------------------------- =' 2.5
'Nominal Escalation Rate of O&M [%] ---------------------- =' 2.5
'Nominal Escalation Rate of Fuel Cost [%] ---------------- =' 3.0
'Nominal Escalation Rate of EnvirCosts [%] --------------- =' 0.0
'Nominal Escalation Rate of Revenues [%] ----------------- =' 3.0
'Levelization(0=no;1=yes) -------------------------------- =' 0
'Levelization discount Rate [%] -------------------------- =' 2.5
'Levelization time period [year] ------------------------- =' 10
'Construction beginning year(1Jan) ----------------------- =' 2000
'Construction period [year] ------------------------------ =' 2
'Nominal Escalation Rate of PEC [%] ---------------------- =' 2.5
'Economic analysis type (0=current money, 1=constant money) =' 0
'Zero Year (only for constant money analysis) ------------ =' 2000
'Allocation of Fixed Capital Investment during conp [%]---- =' 50. 50.
'Plant Economic Life (Book Life) [year] ------------------ =' 20
'Plant Life for tax purposes [year] ---------------------- =' 10
'Law depreciation Factors [%] ---------------------------- =' 10. 10. 10. 10. 10.
'Depreciation method (1,2,3,4,5) ------------------------- =' 1
'Debts           -financing fraction [%] ----------------- =' 50.
'Preferred stocks-financing fraction [%] ----------------- =' 15.
'Common equities -financing fraction [%] ----------------- =' 35.
'Debts           -Required annual return [%]--------------- =' 5.5
'Preferred stocks-Required annual return [%]--------------- =' 6.
'Common equities -Required annual return [%]--------------- =' 6.5
'Average Income tax rate         [%] --------------------- =' 30.
'Average Property tax rate [% of FCI-LAND]---------------- =' 1.5
'Average Insurance rate [% of FCI-LAND]------------------- =' 0.5
'Discount rate for investment parameters ----------------- =' 2.5
'Salvage value  [%FCI] ----------------------------------- =' 0.0
_______________________________________________________________________

' 1. Startup costs [5-12% of FCI] -------------------------- =' 0.
' 2. Working capital [15-30% of FCI] ----------------------- =' 0.
' 3. Costs of licensing, research and development [7% of FCI] =' 0.
' 4. Engineering and supervision [25-75% of PEC] ------------ =' 0.
' 5. Construction costs COCO [15% of DC] -------------------- =' 0.
' 6. Contingencies [8-25% of ES+COCO+DC] -------------------- =' 0.
' 7. Land [0-10% of PEC] ------------------------------------ =' 0.
' 8. Civil structural and architectural work [15-90% of PEC]  =' 15.
' 9. Service facilities [30-100% of PEC] -------------------- =' 30.
'10. Purchased equipment cost installation [20-90% of PEC] -- =' 20.
'11. Piping [10-70% of PEC] --------------------------------- =' 10.
'12. Instrumentation and controls [6-40% of PEC] ------------ =' 6.
'13. Electrical equipment and materials [10-15% of PEC] ----- =' 10.
_______________________________________________________________________

ATTENTION: the following data must be referred to the Economic Data Reference Year
           (for consistency with all the component cost equations)

'Sale Price for Electric Power [$/KJ]  ---------------------- =' 1.29E-5
'Sale Price for Thermal Power [$/KJ]   ---------------------- =' 4.5E-6
```

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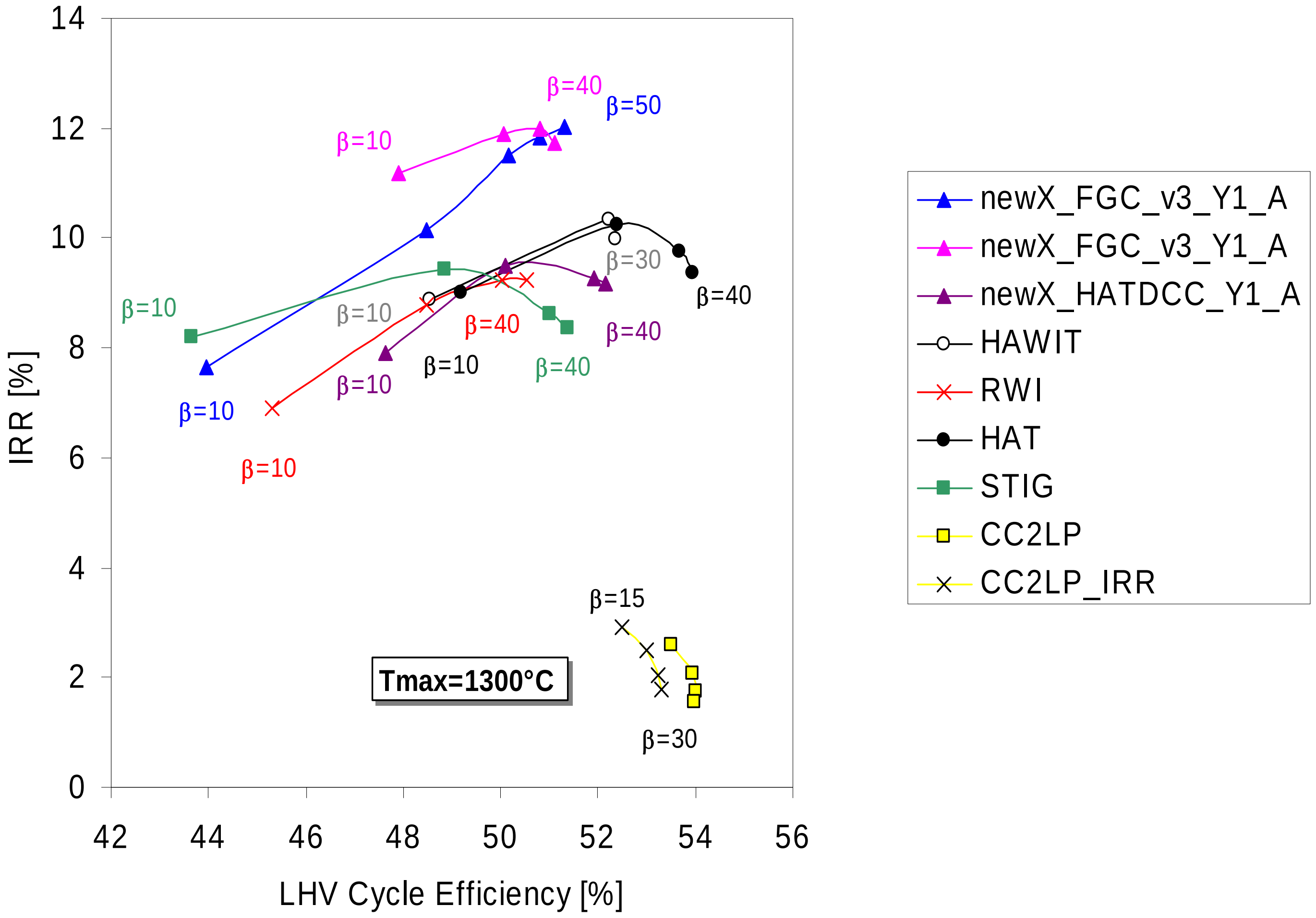
THERMOECONOMIC RESULTS (50MWe)



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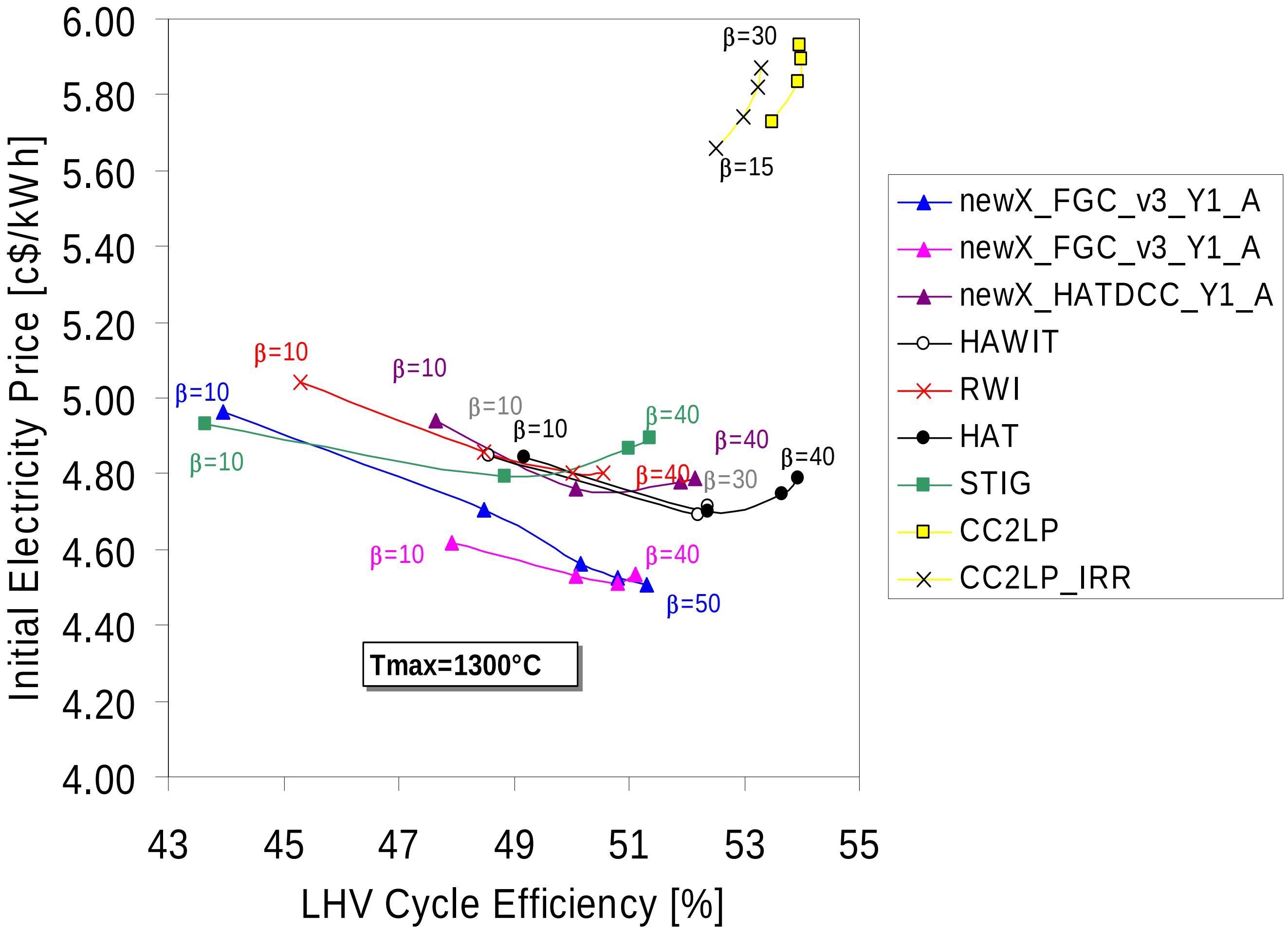
THERMOECONOMIC RESULTS (50MWe)



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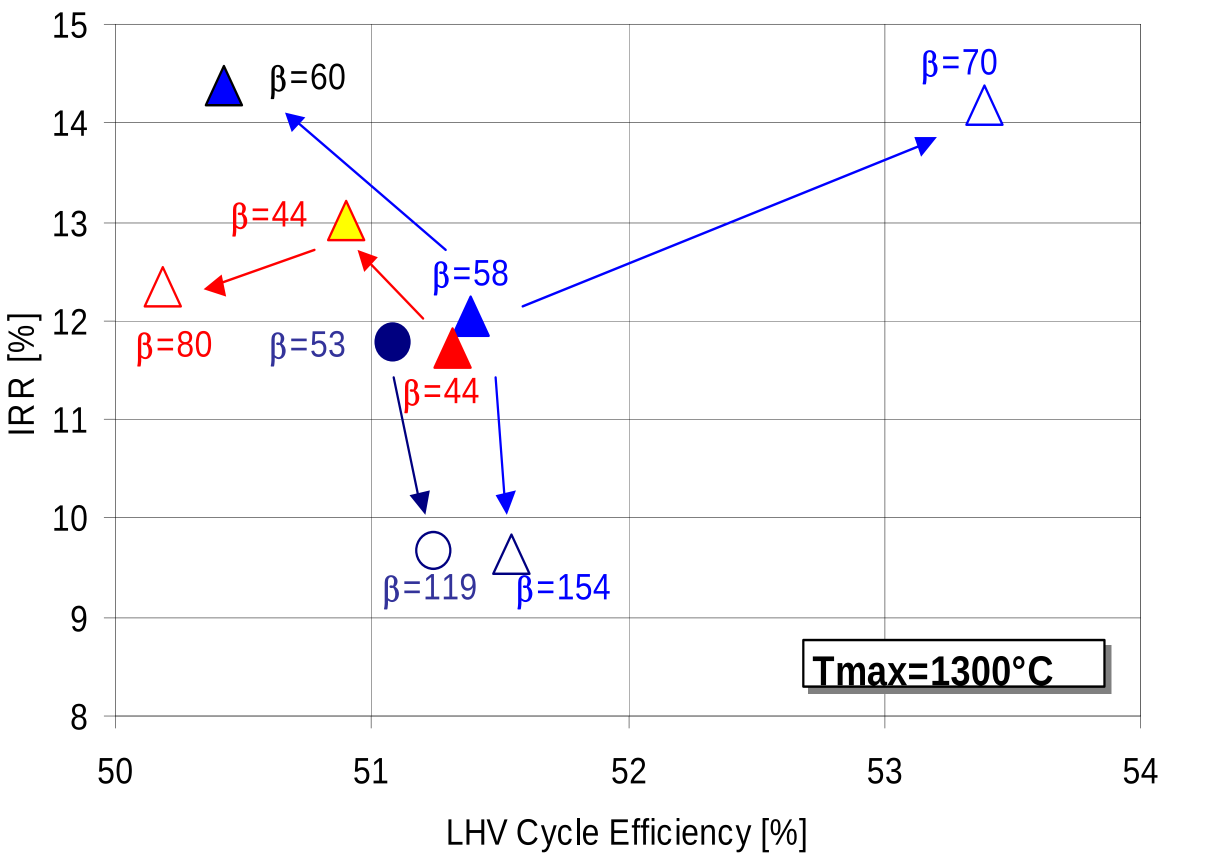
THERMOECONOMIC RESULTS (50MWe)



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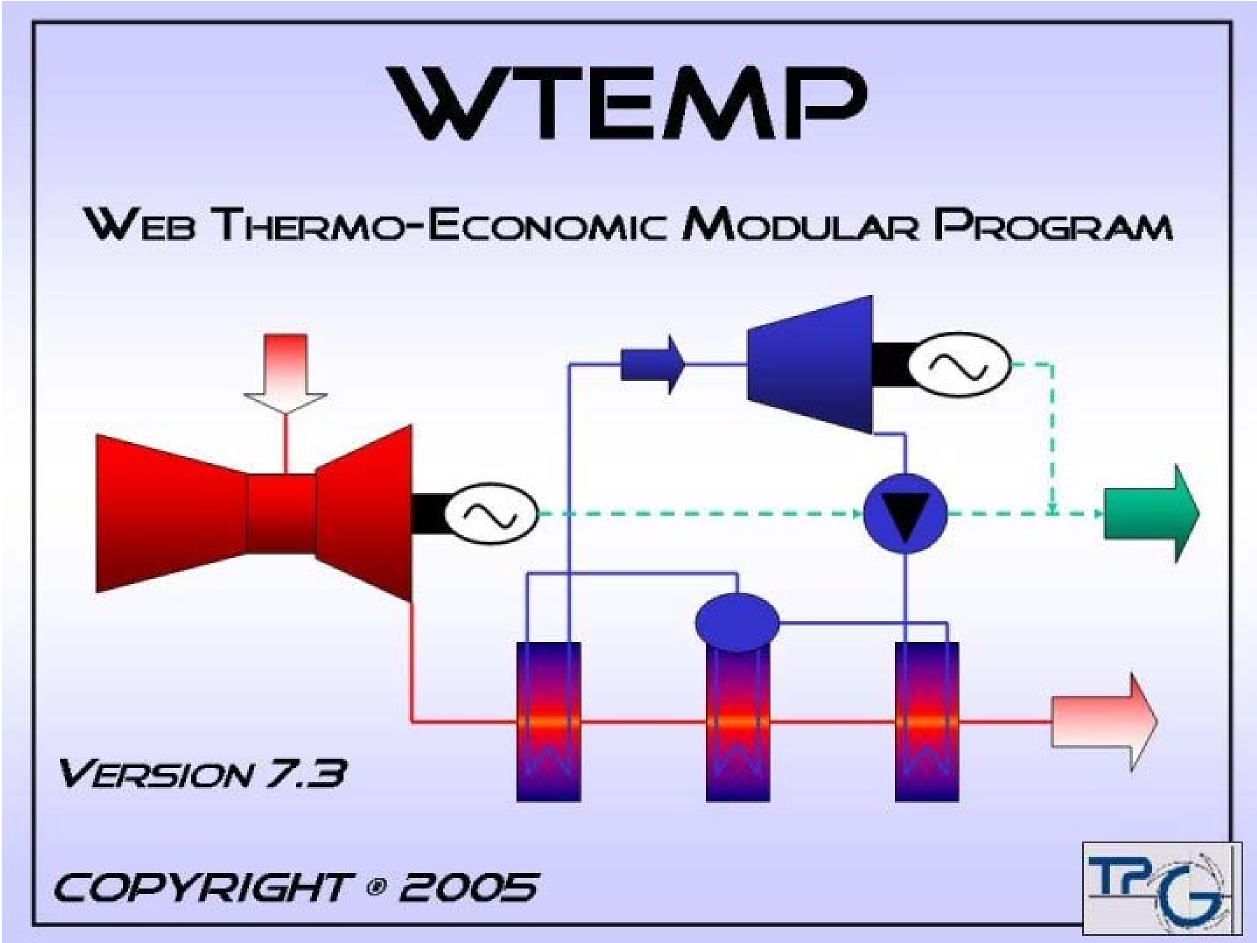
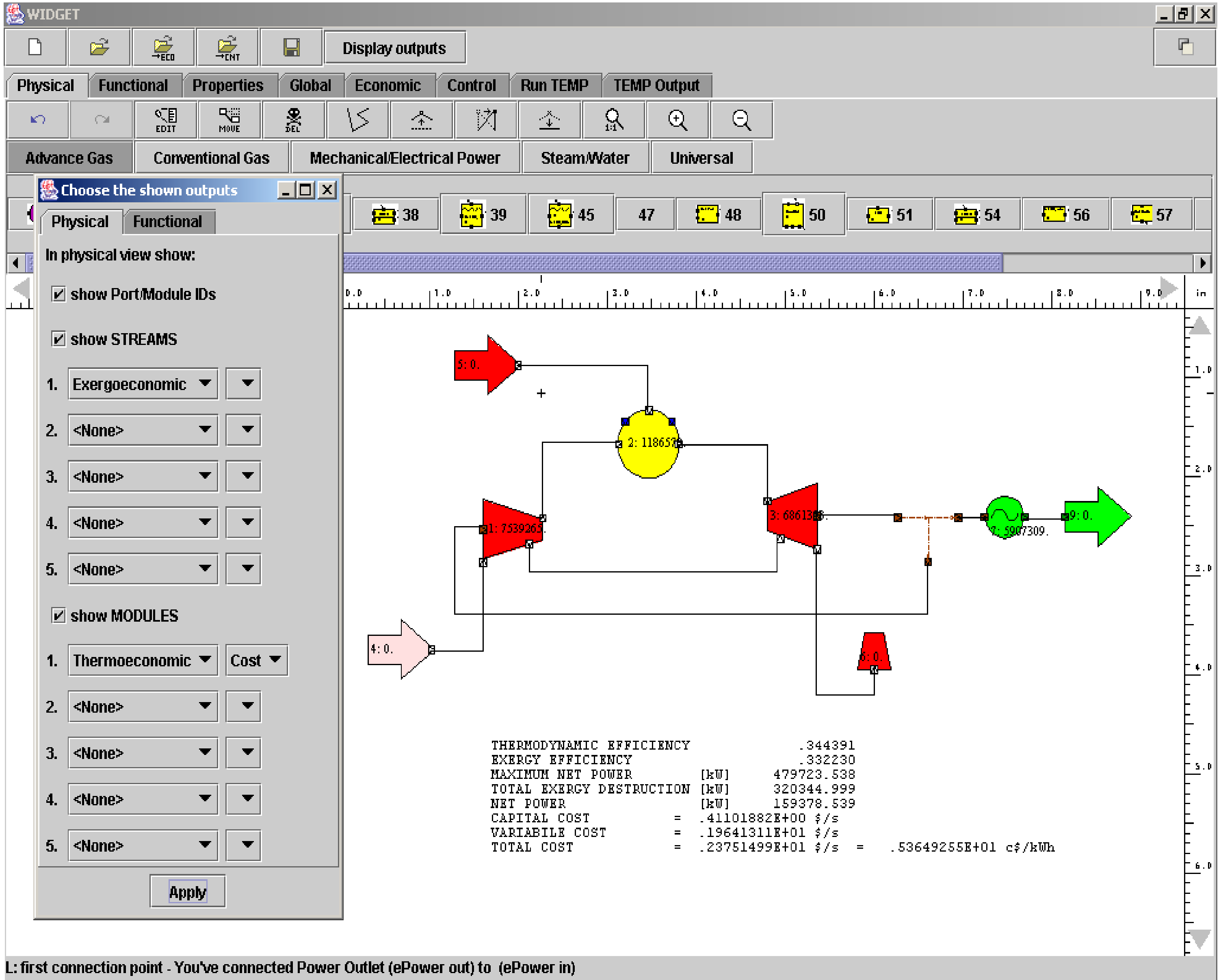
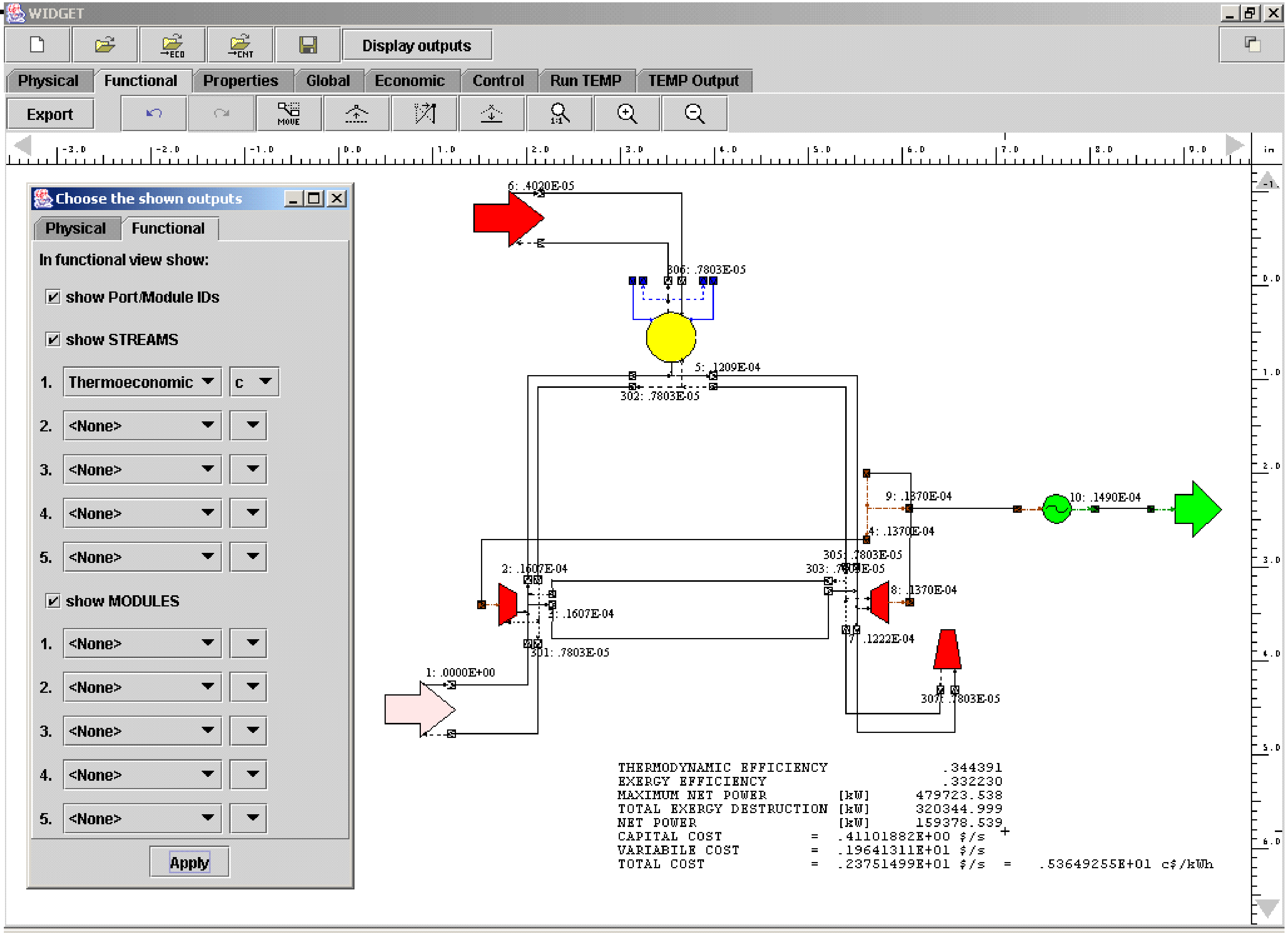
Part III:



Client/server architecture


WIDGET
Display outputs
Physical
Functional
Properties
Global
Economic
Control
Run TEMP
TEMP Output
Advance Gas
Conventional Gas
Mechanical/Electrical Power
Steam/Water
Universal
Choose the shown outputs
Physical
Functional
In physical view show:
show Port/Module IDs
show STREAMS
1. Exergoeconomic
2. <None>
3. <None>
4. <None>
5. <None>
show MODULES
1. Thermoeconomic
Cost
2. <None>
3. <None>
4. <None>
5. <None>
Apply
THERMODYNAMIC EFFICIENCY .344391
EXERGY EFFICIENCY .332230
MAXIMUM NET POWER [kW] 479723.538
TOTAL EXERGY DESTRUCTION [kW] 320344.999
NET POWER [kW] 159378.539
CAPITAL COST = .41101882E+00 $/s
VARIABILE COST = .19641311E+01 $/s
TOTAL COST = .23751499E+01 $/s = .53649255E+01 c$/kWh
L: first connection point - You've connected Power Outlet (ePower out) to (ePower in)


WIDGET
Display outputs
Physical
Functional
Properties
Global
Economic
Control
Run TEMP
TEMP Output
Export
Choose the shown outputs
Physical
Functional
In functional view show:
show Port/Module IDs
show STREAMS
1. Thermoeconomic c
2. <None>
3. <None>
4. <None>
5. <None>
show MODULES
1. <None>
2. <None>
3. <None>
4. <None>
5. <None>
Apply
6: .4020E-05
306: .7803E-05
5: .1209E-04
302: .7803E-05
9: .1370E-04
10: .1490E-04
4: .1370E-04
305: .7803E-05
2: .1607E-04
8: .1370E-04
3: .1607E-04
7: .1222E-04
301: .7803E-05
1: .0000E+00
307: .7803E-05
THERMODYNAMIC EFFICIENCY .344391
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TOTAL COST = .23751499E+01 $/s = .53649255E+01 c$/kWh

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W-TEMP

New cost equations for GTs

$$\Xi_{compressor} = c_1 \left[\left(\frac{\dot{m}_{air} \cdot \sqrt{R_{in} T_{in}}}{P_{in} \cdot \dot{m}_{ridcr}} \right) \Big/ \left(\frac{\dot{m}_{air} \cdot \sqrt{R_{in} T_{in}}}{P_{in} \cdot \dot{m}_{ridcr}} \right)_{ref} \right]^{c_3} \cdot \frac{\beta^{c_4} \ln(\beta)}{\left(1 - \eta_{pol}\right)^{c_2}}$$

$$\Xi_{combustor} = c_1 \left[\frac{(\dot{m}_{gout} \cdot V_{out})}{(\dot{m}_{gout} \cdot V_{out})_{ref}} \right]^{c_5} \cdot \left[1 + e^{\left(c_3 \cdot \left(\frac{T_{out}}{T_{out\,ref}} \right) - c_4 \right)} \right] \cdot \frac{1}{\left(1 - \frac{P_{out}}{P_{in}} \right)^{c_2}}$$

$$\Xi_{turbine} = c_1 \left[\frac{(\dot{m}_{gout} \cdot V_{out})}{(\dot{m}_{gout} \cdot V_{out})_{ref}} \right]^{c_5} \left[1. + e^{\left(c_3 \cdot \left(\frac{T_{in}}{T_{in}ref} \right) - c_4 \right)} \right] \cdot \frac{\ln(\beta_t)}{\left(1 - \eta_{pol}\right)^{c_2}}$$

$$\Xi_{generator} = c_1 \cdot \left(\frac{Pow_{el}}{Pow_{el}ref} \right)^{c_2}$$

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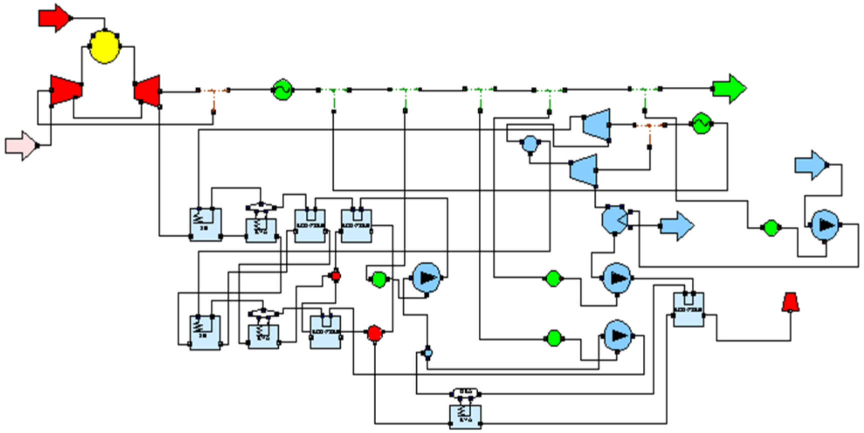
W-TEMP

Improved accuracy of thermoeconomic predictions

Combined Cycle



Error on thermodynamic results: ±2%

	V94.2 Gas Turbine		1.V94.2 Combined Cycle	
	Available data	WIDGET-TEMP results	Available data	WIDGET-TEMP results
Net Power [kW]	159400	159380	232900	236826
Efficiency [%]	34.4	34.4	51.7	51.23
GT Pressure ratio	11.4	11.4	11.4	11.4
Intake air [kg/s]	509	500	509	500
Turbine Outlet Temperature [°C]	547	545	547	552
Capital Cost [10^6 $]	24.7	26.3	103.87	102.5
Specific Cost [$/kW]	155	170	446	433

Error on economic results: ±3%

Objectives:

Part I: **Description of TEMP**

Part II: **Example of thermoeconomic analysis**

Part III: **Description of W-TEMP**

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Dipartimento di Ingegneria Meccanica - DIME